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REMARKS

Claims 1-18 are pending in this application.

Claims 14-15 are withdrawn from consideration.

Claims 1-13 and 16-18 are rejected.

Claims 3 and 4 are rejected under 35 U.S.C 112, first paragraph, for failing to comply with the enablement requirement.

Claims 3 and 4 have been cancelled to expedite allowance of this application.

Claim 1 has been rejected under 35 U.S.C. 102(e) as being anticipated by Coroy, 6,492,704.

Claim 1 is rejected under 35 U.S.C. 102(b) as being anticipated by Goossen et al. 4,904,859.

In order to expedite allowance of this application, Applicant has cancelled claim 1 without prejudice.

Claims 2, and 5 through 9 are rejected under 35 U.S.C. 102(b) as being anticipated by Goossen et al. 4,904,859.

Claims 2 through 5 have also been cancelled without prejudice so as to expedite allowance of this application.

In the office action, Goossen et al., U.S. 4,904,859, are said to disclose a semiconductor device (photodiode) 110

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comprising an intrinsic layer (semiconductor intrinsic light absorption layer), I, p-type region (p-doped light absorption layer) 111, n-type contact region (n-doped absorption layer) 112 and contact pads (cathode electrode and anode electrode) 116, 117.

The Examiner states that Goossen discloses the intrinsic layer comprising a quantum well region 114 being 500 A, GaAs spacer layer 115 being 500 A, and intrinsic spacer layer 113 being 500 A, respectively. It is further said in the office action that these thicknesses clearly disclose the relationship (tp+tn)ti is greater or equal to 0.17, since the p-type is many times greater already than the intrinsic layer.

The Applicant would like to point out that Goossen et al. do not disclose a semiconductor photodiode that has P-I-N layers. Goossen et al. describe an electro-optic modulator, which is a binary device that switches between an on state and an off state. In Goossen et al (4,904,859) his electro-optic modulator has layers 111 and 112, both of which are doped, and yet neither absorbs light due to its higher bandgap; only narrow bandgap materials absorb light. The abstract, description and claims of the '859 patent reinforce the fact that the PIN is comprised of said first and second layers comprising wide bandgap semiconductor material, said subregion comprising at least one layer of substantially narrow bandgap semiconductor material. Both the p and n regions are defined specifically to be wide bandgap regions. These regions are clearly non-light absorbing by definition. Goossen et al's intrinsic layer is a substantially narrow bandgap layer but their p-doped and n-doped regions are wide bandgap and non-light absorbing.

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A low or narrow bandgap, light-absorbing semiconductor has a bandgap lower than photon energy, and a wide or high bandgap non-light-absorbing semiconductor has a bandgap higher than photon energy, where photon energy is defined as $E_{ph}=1.239eV\mu m/\lambda$

At the conclusion of the Goossen et al disclosure related to a modulator, the following and only reference is made to a photodiode.

"Other configurations of the device 110 are contemplated within the spirit and scope of the present invention. For example, it is understood that the present invention is extensible to devices in which the resistor is integrated with the p-i-n diode. Also, a compound p-n-p-i-n structure is contemplated in which the p-n diode forms the photodiode and the p-i-n structure is the integrated modulator including the asymmetric quantum well region. It is further understood that the use of asymmetric quantum well regions is contemplated for all forms of self electrooptic effect devices such as the asymmetric SEED and the asymmetric SEED." (underlining added for emphasis).

It is clear from reading Goossen et al that they define an electro-optic modulator, which runs essentially in two-states. Light absorption not taught with regard to the p-n regions; and their PIN device is modulator not a light absorbing photodiode. In fact the word "light" and the word "absorption" do not appear at all in the Goossen et al. reference. The text above, which describes an extension to the modulator invention, by including an integrated

photodiode, teaches the photodiode to be a p-n device, devoid of having an intrinsic region. In Goossen et al's device, their p-doped and n-doped regions have tp=tn=0, according to the definition of tp and tn in the applicant's claim, which call for them to be "light absorbing".

In summary, Goossen et al do not disclose:

a) a "p-i-n" photodiode;

b) a p-doped light absorption layer;

c) an n-doped light absorption layer;

Applicant's claims are all limited to at least

A heterojunction photodiode comprising: a) a semiconductor intrinsic light absorption layer having a thickness t_i;

b) at least one of a p-doped light absorption layer and an n-doped light absorption layer; wherein the p-doped light absorption layer has thickness t_p and the n-doped light absorption layer has a thickness t_n, and wherein $(t_p + t_n)/t_i$ is greater or equal to 0.17, wherein $t_i > 0$; and wherein at least one of the p-doped light absorption layer and the n-doped light absorption layer have a doping concentration of d_c between 1e16 and 5e18 cm^{-3} and wherein the concentration of any doping present in the intrinsic layer is 3e15 cm^{-3} or lower; and

c) a cathode electrode and an anode electrode electrically couple with the n-doped light absorption layer or the p-doped light absorption layer, respectively.

Amended claim 6 now defines a heterojunction photodiode.

None of the prior art references disclose the photodiode defined in claim 6 above.

Claims 2 and 5 through 13 are rejected under 35 U.S.C. 103(a) as being unpatentable over Bigan et al. 5,073,809, as applied to claim 1 and further in view of Pankove et al. The Examiner suggests that, although Bigan does not disclose the p-doped light absorption layer and the n-doped absorption layer, having a doping concentration in between 1e16 and 5e18 cm^{-3}, Pankove discloses a PIN semiconductor device comprising a P type first doped layer 13 and N type doped layer 15 with both layers having concentrations of greater than 10e18 cm^{-3}.

The Examiner further suggests that it would have been obvious to one of ordinary skill in the art at the time of the invention to have the p-doped light absorption layer and the n-doped light absorption layer having a doping concentration of in between 1e16 and 5e18 cm^{-3}, in order to form the adequate p-doped layers and n doped layers in a PIN device, since it has been held that where the general conditions of a claim are disclosed in the art, discovering the optimum working ranges involves only routine skill in the art.

Applicant respectfully disagrees with the Examiner on several points. First, it should be understood that Pankove discloses a semiconductor device that works essentially <u>oppositely</u> to Applicant's photodiode. A photodiode is a device which, by definition, converts light to electrical current. A photodiode as described in the present application should absorb light and convert it to an electrical signal.

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Pankoff's LED is a essentially a laser or light-emitting device which must be transparent, not light-absorbing; whereas a photodiode must be light-absorbing.

Hence, anyone concerned with the design of a high speed high responsivity bandwidth photodiode would not look to combine any teachings of Pankoff with other teachings in the field related to photodiodes. The Applicant would also like to point out that all semiconductor layers are not light absorbing. Pankoff's device would suffer from having light absorbing n-doped or p-doped layers. Also, neither of Pankove's layers 13 and 15 has a small enough band-gap to absorb light.

Bigan does not disclose a p-doped or n-doped absorption layer anywhere in his teachings. Figures 4A, 4B, 6A, 6B and 7 and 9A clearly show that the doped layers have wide band-gaps, and are, therefore by definition, not light-absorbing. The light-absorbing layers are intrinsic quantum wells with no intentional doping.

Bigan in 5,073,809 is also absent any teaching of a light absorbing n-doped or p-doped layer, as his device ideally would have light absorption that is switched on and off by applied voltages across the intrinsic region only. The ideal modulator gives the highest extinction, namely, it minimizes light absorption and maximizes transparency, when it is on, and it maximizes light absorption and minimizes transparency, when it is off. The optimized modulator certainly will not have any constant light absorption at all. The electrically modulated change in light absorption results in the electro-optical modulator. This modulation cannot, in principle, be

achieved in any doped layer(s), since doped layers cannot sustain electric fields across it. Bigan's main figure, Figure 9A, illustrates this.

Bigan discloses a modulator which is an on-off switching device. Aside from there being no suggestion of combining Pankove and Bigan, such a combination would certainly not yield the hetero-junction photodiode defined in amended claim 6. Both references are lacking the essential features defined in applicant's claim 6 and, if one were inclined to combine these references, the resulting device would not be the photodiode now claimed in this instant application.

A hindsight substitution or combination of portions of teachings of a semiconductor laser, with a semiconductor modulator with a semiconductor photodiode, is simply not proper and, regardless, would not yield the Applicant's invention as defined in independent claim 6.

Applicant would like to provide the Examiner with some background to the instant invention which may be useful in understanding the significant advance provided by the invention defined in the claims, in view of all prior art known to applicant.

Before the birth of hetero-junction photodiodes, namely, photodiode devices that consisted of different types of semiconductor materials, all photodiodes were homo-junction devices, that is, devices that are made essentially in one and the same type of semiconductor material except for doping. In this instance a difference in doping does not yield a different semiconductor material. This is the primary

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structure discussed by Coroy. These photodiodes had their speeds limited typically to 512 M bits/second or below, and produced quantum efficiencies much less than 100%. At their inception, these devices may have been referred to as "high-speed" devices. However, by today's standards, one can rarely find anyone suggesting or marketing a device as high-speed, unless it has a speed of at least 10 G bits/second.

To applicant's knowledge, for applications at 2 G bits/second or higher, the photodiode has to be a hetero-junction device. Compared with homo-junction devices, the hetero-junction device dramatically improved the speed as well as the quantum efficiency and responsivity of the photodiode. Essentially the same hetero-junction photodiode design has been used from 2 G bits/second to 10 G bits/second, to 40 G bits/second, and now to 100 G bits/second.

As the speeds of photodiodes keep increasing, it is found that even these great hetero-junction photodiodes start to exhibit a tradeoff between responsivity and speed. The so-called "theoretical limit" for modern high-speed hetero-junction p-i-n photodiodes says that the product of its responsivity and its bandwidth cannot exceed a certain upper limit. This well-accepted responsivity-bandwidth-product is documented in most textbooks on modern high-speed semiconductor photodiodes, and is frequently cited by countless literature and patents. Listed below are some of the large number of literature references with numerous designs within this "theoretical limit".

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An asymmetric twin-waveguide high-bandwidth photodiode using a lateral taper coupler
Fengnian Xia; Thomson, J.K.; Gokhale, M.R.; Studenkov, P.V.; Jian Wei; Lin, W.; Forrest, S.R.;
Photonics Technology Letters, IEEE
Volume 13, Issue 8, Aug. 2001 Page(s):845 - 847
Digital Object Identifier 10.1109/68.935823

A high-responsivity high-bandwidth asymmetric twin-waveguide coupled InGaAs-InP-InAlAs avalanche photodiode
Jian Wei; Fengnian Xia; Forrest, S.R.;
Photonics Technology Letters, IEEE
Volume 14, Issue 11, Nov. 2002 Page(s):1590 - 1592
Digital Object Identifier 10.1109/LPT.2002.803894

High-efficiency waveguide InGaAs pin photodiode with bandwidth of over 40 GHz
Kato, K.; Hata, S.; Kozen, A.; Yoshida, J.-I.; Kawano, K.;
Photonics Technology Letters, IEEE
Volume 3, Issue 5, May 1991 Page(s):473 - 474
Digital Object Identifier 10.1109/68.93883

Waveguide photodiode
Kato, K.;
Lasers and Electro-Optics Society Annual Meeting, 1997. LEOS '97 10th Annual Meeting. Conference Proceedings., IEEE
Volume 1, 10-13 Nov. 1997 Page(s):158 - 159 vol.1
Digital Object Identifier 10.1109/LEOS.1997.630566

The key design of the textbook hetero-junction p-i-n photodiode lies in the separation of two doped non-light-absorbing semiconductor layers (labeled by "p" and "n", respectively) from the intrinsic light-absorbing semiconductor layer (labeled by "i") sandwiched between the p and n layers. Current design teaching would teach away from having a doped absorption layer, since it is known from the era of homo-junction photodiodes that doped absorption layers <u>reduce</u> responsivity, as well as <u>limit</u> the photodiode speed to less than 512 M bits/second.

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The instant invention defining doped absorption layer goes directly against the current thought and teachings in design of hetero-junction photodiodes.

This invention relates directly to using doped light-absorption layers in high-speed semiconductor photodiodes operating at a minimum of 10 G bits/second and above. With the teaching in this patent application, a proper design of the inventive p-i-n photodiode shall have either higher responsivity than conventional p-i-n photodiodes without doped light-absorption layers, or higher speed than conventional p-i-n photodiodes without doped light-absorption layers, or both simultaneously.

Quite surprisingly, as a result of the present invention, the previous "theoretical limit" has been surpassed.

In summary, Applicant believes that amended claim 6 defines a novel and inventive photodiode that is not suggested or taught in any of the aforementioned prior art references.

In view of the foregoing amendments to the claims, it is respectfully submitted that the instant application is now in condition for allowance.

Early and favorable reconsideration of the Examiner's objections would be appreciated.

Should any minor informalities need to be addressed, the Examiner is encouraged to contact the undersigned attorney at the telephone number listed below.

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Please charge any shortage in fees due in connection with the filing of this paper, including Extension of Time fees, to Deposit Account No. 50-1465 and please credit any excess fees to such deposit account.

Respectfully submitted,

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CERTIFICATE OF FACSIMILE TRANSMISSION

I HEREBY CERTIFY that the foregoing correspondence has been forwarded via facsimile number **571-273-8300** to the COMMISSIONER FOR PATENTS, this 12 day of October 2005.

J. Kallemeres